(51) International Patent Classification 6 : G01N 21/84, 21/86, 21/00, G06K 9/00, H04N 7/18, 9/47	A1	(11) International Publication Number: WO 97/39339
		(43) International Publication Date: 23 October 1997 (23.10.97)

(54) Title: SURFACE DEFECT INSPECTION SYSTEM AND METHOD
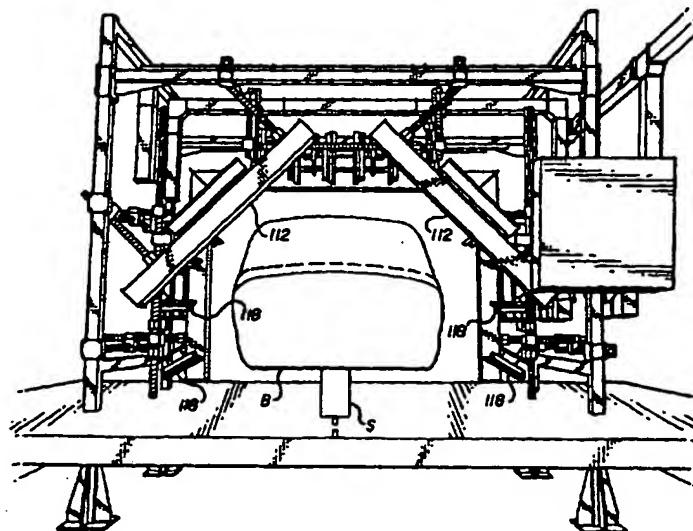
(57) Abstract

A system and method for detecting defects on a painted workpiece surface (B). The system includes an elongated line of light (112) having a pair of sharp transition zones. The line of light falls onto a moving substrate (S) containing a plurality of workpieces (B) to be inspected. A scanning detector (118) receives light scattered by the workpiece (B) surface. A first scan is performed proximate one edge of the line of light (112) and a second scan proximate the other. A defect on the workpiece (B) produces characteristic shadow or backscatter patterns which vary between the first and second scans. The shadow and backscatter patterns cause variations in the amplitude of the light detected by the scanning detector (118). The scanned information is then digitally and electronically processed by software which recognizes each defect, and characterizes the defect by type and/or size.

SURFACE DEFECT INSPECTION SYSTEM AND METHOD

Cross Reference to Related Applications

This application is a continuation-in-part of U.S. Serial No. 08/673,926,
filed July 1, 1996 and presently pending which, in turn, is based on provisional
application No. 60/015,406, filed on April 12, 1996, the disclosure of which is
hereby incorporated by reference.

Field of the Invention

This invention concerns the field of automated inspection systems, and,
particularly, a system and method useful for scanning a painted surface and
detecting defects thereon.

Description of the Relevant Prior Art

Quality control is an important component of automated production
processes. Like the products of the production processes which it scrutinizes,
quality control has become increasingly automated over time. For example,
automated visual inspection systems, rather than human inspectors, are
increasingly being employed to perform repetitive visual scanning of workpieces
in order to detect any flaws therein.

In particular, a number of prior art automated scanning systems have
been developed which are specifically intended to inspect the surface of a
workpiece to detect defects and blemishes in the painted surface thereof. For
example, U.S. Patent No. 5,367,378 to Harding et al. discloses an optical
inspection system and method for evaluating the surfaces of large contoured

2

panels. The method involves providing an illumination means for projecting a pattern of lines having a periodic configuration with features having a separation period. A camera records an image of the pattern of lines as reflected from the surface being inspected. The recorded image is evaluated and quantified by

5   calculating a slope of a defect observed by the camera using a specified mathematical relationship. The distance between the illuminated pattern and the surface are used to calculate the defect slope, and a defect depth value is generated using a specific relationship dependent on the length of the defect area visually recognizable from the reflected image and the calculated defect slope.

10   U.S. Patent No. 5,389,794 to Allen et al. discloses a surface pit and mound detection and discrimination system. The system scans a beam of radiation over the surface to be inspected, and includes a mechanism for separately sensing radiation scattered from the surface in the near and far specular regions in order to differentiate between pits and mounds and other

15   types of defects. The system includes means for detecting a local slope on the surface from radiation scattered from the surface in the near specular region and for differentiating between whether said beam of radiation is scanning a pit or a mound.

U.S. Patent No. 5,461,474 to Yoshii et al. discloses an inspection

20   apparatus for detecting foreign matter on a surface having first and second spaced lines. The surface is scanned by a light beam in a direction orthogonal to the lines, and the size of the light beam is less than the interval between the

3

two lines. The system includes detection means for detecting light reflected from the surface from the scanning and producing first and second signals corresponding to the scan of the first surface line and the second surface line, respectively. Signal processing means are provided for processing a correlation

5   between the first and second signals and detecting whether foreign matter exists on the surface. This system is particularly useful for inspecting semiconductor devices having a circuit pattern formed thereon. The "first and second lines" on the surface to be inspected are, thus, part of the circuit pattern. The system has no particular utility for inspecting surfaces which do not include orthogonal

10   patterns of lines and which contain defects which do not isotopically scatter impinging light. Such limitations render this system particularly unsuitable for inspecting irregular parts having large painted surfaces.

      U.S. Patent No. 4,918,321 to Klenk et al. discloses a method for the detection of blemishes on the surface of the object. The system uses a strip of

15   light which is moved over the surface of the workpiece. Striplike sections of the surface being inspected are in each case recorded stepwise in the region of the strip of light, the step size of successive recordings being smaller than the width of the strip of light. The light reflected from the surface is directed onto an opto-electronic video camera by means of a movable reflecting means which

20   controls the increment of movement between adjacent images. Since the Klenk system relies on a movable reflecting means, this creates the difficult problem

4

of coordinating movement of the reflecting means over the surface of the workpiece if the surface is curved and complex.

U.S. Patent No. 5,237,404 to Tanaka discloses a surface defect inspection system which interrogates the workpiece surface with radiating light
5   having a predetermined change pattern. A camera is arranged for receiving an image of the irradiating, structured light which is reflected by the surface. The structured light contains gradations in intensity. The system looks for disruptions in the pattern of the structured light by taking partial derivatives of the wave form of the video signal.

10   Ideally, an automated system useful for inspecting workpieces having painted surfaces, such as vehicle body panels, should possess several important characteristics. First, the system should be able to isolate and detect individual flaws in the painted surface such as are caused by dirt or other foreign substances, pinholes or scratches in the paint finish, etc. Thus, it is important
15   that the system be able to distinguish between defects which are raised or elevated above the paint surface (often caused by dirt or other foreign particles) and defects which are depressed below the nominal paint surface (such as caused by interruptions in the paint coat). Furthermore, it would be highly advantageous if such a system were able to characterize the defects by size so
20   that only those body parts having defects larger than a certain reference size would need to be rejected.

5

Many painted workpieces such as vehicle body panels have certain structural features, such as, for example, cutouts for the door handle on a side body panel. Each such panel can be expected to have the same cutout in the same location. Thus, it would be highly desirable for an automated inspection

5   system to be able to distinguish between these expected interruptions in the surface and true defects.

Summary of the Invention

The present system and method have been designed to provide the desirable characteristics of an automated inspection system described above.

10   Disclosed herein is a system and method for detecting defects on a surface, and particularly on a painted surface such as an automobile body panel. The system is capable of characterizing surface defects in a number of ways, including by size of the defect and by surface elevation of the defect (that is, whether it is a crater or a piece of foreign matter). The system is also capable of "learning"

15   to recognize known features on the workpiece, such as, for example, a cutout for a door handle on a side auto body panel.

The system of the present invention comprises three main parts. The first part is the optical components, including a light source capable of projecting a line of light having leading and trailing edges or transitions from

20   dark to bright. In one embodiment, the light source is a diffuse light source which radiates light through a slit to produce a line of light. The width of the slit is chosen with some care to meet the dual criteria of being wide enough that

the surface roughness of the paint on the workpiece to be inspected (the "orange peel") does not throw a shadow, yet narrow enough that the more severely sloped dirt particles and craters do throw shadows. The system uses differences in the intensity of the light reflected back from the surface of the workpiece to detect dirt or other foreign particles in the paint. It would be undesirable for the system to mistake natural surface roughness of the paint for actual defects. In one embodiment, the system detects shadows cast by defects. In an alternate embodiment, the system detects light backscattered by dirt or other foreign particles in the paint. In yet another embodiment, the system detects both shadows cast by defects and the light backscattered by defects.

A moving substrate carries a succession of workpieces in a linear direction, the direction of travel of the substrate being perpendicular to the line of light projected from the light source. Thus, workpieces that are traveling on the substrate will sequentially pass through the line of light at right angles with respect thereto. Any given position on a workpiece will first pass through the trailing edge of the projected line of light and subsequently through the leading edge thereof.

A detector is provided which scans in a direction parallel to the line of light. Since the workpieces travel in a direction perpendicular to the line of scan, the detector will successively scan all portions of each workpiece as the workpiece travels along with the substrate. The detector is further operative to produce signals which vary as the amplitude of the light scattered (either

7

reflected and/or backscattered) by the surface onto the scanner varies in amplitude. In a preferred embodiment, the scanner is a charge coupled device detector including a linear array of charged coupled devices.

In the embodiment of the invention in which defects are detected by the
5   shadows they throw, each location on the workpiece is scanned at least twice while traveling through the line of light. A first scan is made when the location is in the line of light and proximate the trailing edge thereof; a final scan is made when the location is proximate the leading edge of the line of light.

In the embodiment of the invention in which defects are detected by the
10   light which they scatter back into the scanner, each location on the workpiece is scanned at least twice while traveling outside the line of light.

The system of the present invention further includes means for adjusting the image processing to the rate of travel of the substrate. Depending on the production environment, the substrate may travel at varying rates of speed. The
15   faster that the substrate (and workpieces carried thereon) travels, the further each location on a workpiece will travel during one scan of the detector. In the embodiment of the invention in which defects are detected by shadows they throw, Δ_t (the time interval between scans) must be less than one-half the time it takes a location on the workpiece to travel from a position proximate the
20   leading edge of the line of light to a position proximate the trailing edge thereof.

The second portion of the system is image processing equipment. First, the signal produced by the detector is digitized. The signals are converted from

8

a two-dimensional data stream into a three-dimensional array by providing

memory locations corresponding to each position on a three-dimension array in

which the digital data is stored.   If there is a defect at a location on the

workpiece, the defect causes a variation in the amplitude of the light scattered

5   from the workpiece surface onto the detector.   This variation in amplitude is

detected by the scanner, digitized, and stored as described.   Moreover, because

the defect is scanned at least twice, each defect generates two separate sets of

digital data, both of which are stored by the system.   However, because the

angle of light incident on the defect is different for each of the two scans (since

10   the defect is moving relative to the light source), the two sets of data

representing shadows cast by the defect in one embodiment, or light

backscattered by the defect in another embodiment, in the first and second scans

are slightly different.

The data is subjected to further digital processing in order to perform a

15   correlation between the output signals from the scanner gathered during the two

scans.   In one embodiment of the system and method of the present invention,

the two sets of scan data are first passed through a finite impulse response filter

(FIR) whose characteristic spatial frequency response is tuned to the rate of

travel of the substrate.   This serves to isolate and amplify the variation in

20   amplitude caused by the defect.   The filtered signals are then subjected to a

subtraction (one set of data is subtracted from the other) to achieve a composite

set of data.   However, it is to be understood that these steps of filtering and

9

subtracting may be performed in reverse order, in certain cases, so that the subtraction operation is performed first, and the composite signal is then passed through the FIR.

After the image has been processed, it is then subjected to the third
5   element of the system, namely, post processing. Post processing is performed in a computer programmed with a software program capable of recognizing processed image data which represents defects, and classifying defects so identified by a particular characteristic, such as size, or surface elevation. For example, if the defect is a crater, then it will cast different and unique shadow
10   patterns in each of the first and second scans, resulting in a characteristic composite shadow pattern unique for craters. The characteristic patterns for craters are stored in the software. The program compares the processed image data with the stored data and determines whether the defect is a crater. The software can also store characteristic shadow patterns for other types of defects
15   (such as bumps or pieces of foreign debris) so that the software can compare the processed image data and, again, determine whether the defect is an elevated defect.

The post processing software is also capable of being "taught" to recognize known surface variations in the workpieces. The system of the
20   present invention can be used in a trial run with a plurality of workpieces (such as auto body side panels) which all have, for example, a door handle cut out in the same position. The post processing software can identify this particular

10

characteristic on every workpiece and learn to expect it in a particular workpiece

location. After the trial run, the system will subtract this known characteristic

every time it processes the images for a new workpiece since the software has

"learned" to expect this particular feature in this particular location. Since the

5   system of the present invention is capable of learning to distinguish expected.

surface variations from unexpected ones, it can be used to inspect a wide variety

of workpiece types, even those which are highly irregular. Thus, the system

and method of the present invention display extreme versatility.

Brief Description of the Drawings

10   The following detailed description is best understood with reference to

the following drawings in which:

Figure 1 is a perspective view of a surface inspection system according

to the present invention;

Figure 2A is a top view of a portion of a moving substrate carrying a

15   workpiece having a defect thereon at time T_0, said defect identified by the

shadow it casts within a band of illumination;

Figure 2B is similar to Figure 2A but shows the position of the defect at

time T_1;

Figure 3A is a representation of a first scan of the defect of Figure 2A

20   at time T_0;

Figure 3B is similar to Figure 3A but represents a second scan at time

T_1;

11

Figure 4 shows the results of the scans of Figures 3A & 3B after they

have been subtracted and passed through a finite impulse response filter;

Figure 5A is a top view of a portion of a moving substrate carrying a

workpiece having a defect thereon at time T_0, said defect identified by the

5   backscattered radiation it returns to the camera;

Figure 5B is similar to Figure 5A but shows the position of the defect at

time T_1;

Figure 6A is a representation of a first scan of the defect of Figure 5A

at time T_0;

10   Figure 6B is similar to Figure 6A but represents a second scan at time

T_1;

Figure 7 shows the result of the scans of Figure 6A and 6B after they

have been subtracted and passed through a finite impulse response filter; and

Figure 8 is a front view of a vehicle inspection installation employing the

15   system of the present invention.

Detailed Description of
the Preferred Embodiments

Throughout the following detailed description, like numerals are used to

reference the same elements of the present invention shown in multiple figures

20   thereof. Referring now to the drawings, and in particular to Figure 1, there is

shown a perspective view of a surface inspection system 10 constructed

according to the principles of the present invention. The inspection system 10

includes a light source 12 which emits an elongated line of diffuse light 14.

12

Preferably, the source 12 includes a housing 13 containing a linear lamp 15. The housing 13 has an elongated slit 17 formed in the bottom thereof through which the line of light 14 is emitted. Preferably, the width of slit 17 is selected so that it is wide enough that the natural surface roughness or "orange peel" of

5   a painted surface being inspected does not cast a shadow, yet narrow enough that dirt particles, other foreign matter, and breaks in the painted surface do cast shadows.

Preferably, the light source 12 comprises a fluorescent lamp 15 diffused through a thin (.005 inches) sheet of diffusing film, such as that produced by the

10   Plastic Films Company. The fluorescent lamp 15 is driven by a Mercron, Inc. lamp controller at a high frequency (20,000 Hz) so that several periods of light oscillation from the lamp occur during the integration time of the detector. The length of the slit 17 is chosen so that the length of the field of view of detector 18 (preferably, a CCD camera manufactured by Pulnix Corporation) is fully

15   illuminated.

In an alternative embodiment, in which defects are detected by the light they scatter back to the detector 18 rather than the shadows they throw, slit 17 and the sheet of diffusing film may be omitted.

A moving substrate S supports a plurality of workpieces W. The

20   direction of travel (indicated by the arrow) of the substrate S is perpendicular to the line of light 14, and the light source 12 is disposed such that line of light 14 falls onto moving substrate S. Typically, the substrate S will be a conveyor

13

belt or the like which is used to convey a plurality of workpieces W through an
automated production environment.

The line of light 14 has two "edges" or zones of sharp transition from
light to darkness. These edges include leading edge 16 and trailing edge 19.

5   A defect D in the painted surface of workpiece W will, as it is carried along in
the direction of the arrow by substrate S, first pass through the trailing edge 19
of the line of light 14, and subsequently pass out of the line of light 14 through
leading edge 16. For example, in Figure 2A (which shows a detailed view of
a portion of the substrate S with workpiece W thereon), defect D has just

10   entered line of light 14 at time T_0 and lies proximate trailing edge 19. In
contrast, as is shown in the similar view of Figure 2B, a defect D at time T_1 is
about to pass out of the line of light 14 and is now proximate leading edge 16.
If the time interval between the positions of the defect shown in Figures 2A and
2B is Δ_T, then $T_1 = T_0 + \Delta_T$.

15   The scanner 18 is mounted above the moving substrate S and is
positioned so that it views the reflection of the line of light 14 from the surface
of the workpiece W being inspected. In an alternate configuration the scanner
18 is mounted above the moving substrate S and is positioned so that it views
the light backscattered from the surface of the workpiece being inspected by the

20   line of light 14. The scanner 18 is focused on the surface, and its integration
time is set so short that the smallest defect to be detected travels no more than
one pixel during the time of integration of the imaging array. Figures 2A and

14

2B illustrate the images seen by the camera at, respectively, times T_0 and T_1.

The signal from the scanner 18 is digitized in a computer provided with a

combination digitizer/digital-signal-processor, such as is sold by Spectrum, Inc.

In a manner well known in the prior art, the signal from the scanner 18 is

5   converted into a two-dimensional stream of digital data which is then converted

into a three-dimensional array of pixels (arrayed in rows and columns) which

are stored at memory locations in the computer 20.

The system also includes means 22 for adjusting the frequency of

operation of the system. This is done by tuning the image processing algorithm

10   to the rate of travel of the moving substrate S so that when the system performs

a first scan of a location on the workpiece containing a surface flaw (such as the

scan showing the defect D in Figure 2A) at time T_0 it can predict the location

of the surface flaw in a second scan at time T_1 (when defect D is in the position

of Figure 2B). By adapting the image processing algorithm it is meant that the

15   system measures the speed of the moving substrate and tunes the response of the

FIR filter to match the spatial periodicity of a defect on the substrate moving at

the measured speed and sampled at the scan rate of the detector ($\Delta_t = T_0 - T_1$).

The sensitivity of the scanner 18 to disruptions fixed on the workpiece surface

and, thus, moving at the rate of travel of the moving substrate S is maximal.

20   Figure 3A and 3B illustrate, respectively, the correlation of the scan lines

from the two images illustrated in, respectively, Figures 2A and 2B. Figure 3A

is a representation of a scan line (a horizontal slice) from an image showing the

15

defect at time T_0, and Figure 3B is a representation of a scan line showing the same defect D at time T_1. Defect D has moved a distance determined by the speed of the substrate S and the time Δ_T between time T_0 and T_1.

The images shown in Figures 3A and 3B are then subject to further

5   processing. Figure 4 shows a composite image achieved by subtracting the image of Figure 3B from the image of Figure 3A and passing the result through a finite impulse response filter (FIR) designed to detect correlation. This is done electronically using the digital information stored in the computer 20 in a manner known in the prior art. The system is operative to recognize defects

10   when a central peak such as that shown in Figure 4 exceeds a predetermined threshold level.

Post processing of the Figure 4 image can be performed in a number of ways depending upon the application desired. For example, the post processing software can be operative to identify the defects and classify them by size. The

15   defects can also be classified by type; that is, whether they are craters or elevated dirt particles. Craters and bumps cast different shadow patterns which are characteristic of each type of defect. Because each defect is scanned from both sides, two sets of data representing shadow patterns for each defect are produced. These sets of shadow patterns will vary depending upon the surface

20   elevation of the defect. For example, a bump will produce a pair of crescent shaped shadows which curve toward each other. A crater, on the other hand, will produce a reverse shadow pattern; that is, the pair of crescent shaped

16

shadows will curve away from each other. The system of the present invention

can compare the pair of shadow patterns produced by each defect with known

values stored in the computer 20 and perform a closest match search for each

defect detected.

5   Furthermore, the present system can be trained to identify known surface

features of the workpieces to be inspected so that these are subtracted out and

not misidentified as unexpected defects. In order to do this, the system must

scan a number of workpieces having a particular surface characteristic (such as

the cutout for a door handle on a side body automotive panel). The system, of

10   course, will find a "defect" in each such workpiece at the same location and of

the same type. After exposure to a sufficient number of workpieces having this

same surface characteristic, the system will "learn" to expect to find that surface

characteristic at that location in that particular type of workpiece. The system

can then be further programmed to simply ignore the expected surface

15   characteristic, and, instead, count as defects only irregularities which occur in

unexpected locations.

Figures 5A-7 illustrate how the system of the present invention can use

the phenomenon of backscattering, rather than shadowing, to detect additional

defects. In Figure 5A, a defect D lies outside of the line of light. It is located

20   in a first position at time T_0. Figure 5B, which is similar to Figure 2B, shows

the defect having moved to a second position at time T_0 closest to the line of

light. The system 10 performs successive scans of the defect D at times T_0 and T_1.

Figures 6A and 6B illustrate, respectively, the correlation of the scan lines from the two images illustrated, respectively, in Figures 5A and 5B. Figure 6A is a representation of a scan line from an image showing the backscattering defect at time T_0, and Figure 6B is a representation of a scan line showing the same defect at time T_1.

In a manner analogous to the processing done in the case of the shadowed defect of Figure 2A and Figure 2B, Figure 7 shows a composite image achieved by subtracting the image of Figure 6B from the image of Figure 6A and passing the result through a FIR. It should be noted that it is very easy for the system of the present invention to operate to detect both backscatter and shadow defects. This is so because the electronic processing which is performed for the two types of defects can be carried on by using the same algorithms. The only difference between the two types of defect detection is that in one case, the values are all positive, and in the other case they are all negative. Thus, in a particularly preferred embodiment, the system 10 is programmed to perform both types of detection.

The use of backscattered light in defect detection has certain advantages over the detection of shadows cast by defects. The detection of shadowing requires even illumination. This is difficult to achieve because the illumination

18

must be wide, even and bright. It is particularly hard to achieve such even

illumination on a contoured surface.

The detection of defects by shadowing also requires that the detector

receive light which is sharply angled with respect to the plane of the surface.

5   Otherwise, the resolution of the image is compromised. On flat, even surfaces,

maintaining a low angle of incidence and reflection is relatively easy. However,

many workpieces, and particularly automotive body panels, are highly

contoured. The use of shadowing, alone, does not produce completely

satisfactory results under these conditions.

10   In contrast, backscatter merely requires a small source of illumination.

The source does not have to be even or large, but can be any bright source of

diffuse light, such as a simple fluorescent fixture. Moreover, the resolution of

the image does not depend upon a sharp angle. In fact, the light source can be

perpendicular to the surface. Thus, we have found that the detection of defects

15   by employing the present system to detect backscattering detects considerably

more defects than the use of shadowing alone.

There are, in certain cases, some defects that are picked up more easily

by detecting their shadows. This is particularly true of flat surfaces. Hence, an

optimal result may occur if, as previously described, both types of defects are

20   detected. The most expedient way to do this is simply to split the data stream

into two identical portions. The algorithm for detecting backscatter is applied

to one data stream, and the algorithm for detecting shadowing is applied to the

19

other data stream. This requires only slightly more computational time than simply doing either kind of analysis, alone.

Figure 8 is a front view of a vehicle inspection installation, in which a plurality of light sources 112, each with its associated detectors in the form of

5   video cameras 118, are used. The light sources and video cameras are arranged so as to image all portions of an automotive body B which is conveyed through the system by means of conveyor belt substrate S. In the embodiment depicted in Figure 8, the light sources 112 are tented in angular relationship with respect to the auto body B so as to form a sort of "roof" over the succession of

10   workpieces. Alternatively, the light sources 112 could be arranged to form a closed arch over the workpieces. The particular arrangement is not critical so long as the plurality of light sources are placed so that they illuminate each portion of the automotive body passing through the system.

Similarly, the cameras 118 depicted in the Figure 8 embodiment are

15   disposed along each side of the car passing through the system. The cameras 118 are arranged and located so that the light reflected or scattered from the light sources from all portions of the vehicle body will be imaged. The optimum arrangement of the light sources and cameras in any particular installation is considered to be within the ambit of one of skill in the art. Thus,

20   the system illustrated in Figure 8 is simply one possible arrangement out of many, that could be designed.

20

What has been described is a system and method for performing automated inspection to detect dirt and other flaws on the painted surfaces of a succession of workpieces. The system uses a line of light which falls onto a moving substrate carrying the workpieces. A detector is operative to scan

5   across the moving substrate at a scan rate such that two separate scans are performed of each location on the workpiece. The shadows cast by the defects or light backscattered from them cause variations in the amplitude of light scattered by the workpiece surface which are detected by the scanning detector. The signals from the scanning detector are then digitized and subjected to

10   further processing to identify the defects, and characterize them by size and type.

While the present invention has been described with reference to certain exemplifications and embodiments thereof, it is to be understood that the present invention may be otherwise implemented. Thus, one of skill in the art in

15   designing automated scanning systems may vary the depicted and described embodiments without departing from the scope of the present invention. It is the claims appended hereto, and all reasonable equivalents thereof, rather than the exact depicted embodiments and exemplifications, which define the true scope of the present invention.

21

Claims

1   1.   A system for detecting defects on a coated surface, the system

2 comprising:

3   a source of diffuse light arranged as an arch or other straight or

4 curvilinear source for emitting an elongated line of light having a leading edge

5 and a trailing edge onto a moving substrate having a direction of travel oriented

6 perpendicular to said line of light such that said substrate passes therethrough,

7 a workpiece to be inspected being supported by said moving substrate;

8   a detector for scanning said substrate and receiving light scattered by a

9 surface of said workpiece, said detector operative to scan in a direction parallel

10 to said line of light, said detector having a frequency of operation selected so as

11 to scan said each portion of said workpiece at least twice during said

12 workpiece's traversal through the field of view of the detector;

13   means for generating digital signals, including first and second sets of

14 digital signals corresponding to the amplitude of scattered light received by said

15 detector during said two scans of a portion of said workpiece;

16   means for comparing said first and second sets of digital signals to

17 isolate and amplify variations in the amplitude of received light caused by a

18 defect in said workpiece surface; and

19   means for processing said isolated and amplified signal to identify at least

20 one characteristic of said surface defect.

22

1   2.   The system of claim 1 further comprising means for amplifying

2   said differences in amplitude.

1   3.   The system of claim 2 wherein said amplifying means comprises

2   a finite impulse response filter.

1   4.   The system of claim 1 wherein said defect characteristic is size.

1   5.   The system of claim 1 wherein said defect characteristic is surface

2   elevation.

1   6.   The system of claim 1 wherein said detector is a charge coupled

2   device detector.

1   7.   The system of claim 1 further comprising means for comparing

2   said isolated and amplified signal with stored values representing known

3   workpiece surface irregularities so that said system is able to distinguish

4   between known surface irregularities and unexpected surface irregularities.

1   8.   The system of claim 1 wherein said detector is a CCD camera,

2   said two scans of a portion of said workpiece occur during the traversal of said

3   portion of the workpiece through said line of light, and said amplifying means

23

4   comprises subtracting said scans, one from the other, and applying a finite

5   impulse response filter, which is designed to detect correlation at a distance

6   determined by the speed of the workpiece and the time between scans, to the

7   result.

1   9.   The system of claim 8 further comprising means for comparing

2   said isolated and amplified signal with stored values representing known

3   workpiece surface irregularities so that the system is able to distinguish between

4   known surface irregularities and unexpected surface irregularities.

1   10.   The system of claim 1 wherein said detector is a CCD camera,

2   said two scans of a portion of said workpiece occur during the traversal of said

3   portion of the workpiece outside of the line of light, and said amplifying means

4   comprises subtracting said scans, one from the other, and applying a finite

5   impulse response filter, which is designed to detect correlation at a distance

6   determined by the speed of the workpiece and the time between scans, to the

7   result.

1   11.   The system of claim 8 further comprising means for comparing

2   said isolated and amplified signal with stored values representing known

3   workpiece surface irregularities so that said system is able to distinguish

4   between known surface irregularities and unexpected surface irregularities.

24

1   12.   A method for detecting defects on a painted surface, the method

2   comprising the steps of:

3   emitting an elongated line of light having a leading edge and a trailing

4   edge;

5   passing a moving substrate through said line of light in a direction of

6   travel oriented perpendicular thereto, said substrate supporting at least one

7   workpiece to be inspected;

8   scanning said substrate with a detector in a direction parallel to said line

9   of light to receive light scattered by a surface of said workpiece;

10   operating the system at a frequency of operation selected so as to scan

11   each portion of said workpiece at least twice during said workpiece's traversal

12   through the field of view of the detector;

13   generating digital signals, including first and second sets of digital

14   signals corresponding to the amplitude of scattered light received by said

15   detector during, respectively, said first and second scans; and

16   comparing said first and second sets of digital signals to isolate and

17   amplify variations in the amplitude of received light caused by a defect in said

18   workpiece surface to identify at least one characteristic of said surface defect.

25

1   13.   The method of claim 12 wherein the step of amplifying said first

2   and second sets of digital signals comprises passing said first and second sets of

3   digitized signals through a finite impulse response filter.

1   14.   The method of claim 12 wherein the step of identifying said

2   defect characteristic further comprises the step of identifying the size of said

3   defect.

1   15.   The method of claim 12 wherein the step of identifying said

2   defect characteristic further comprises the step of identifying the surface

3   elevation of said defect.

1   16.   The system of claim 12 wherein the step of scanning said

2   substrate further comprises the step of scanning said substrate with a charge

3   coupled device detector.

1   17.   The system of claim 12 further comprising the step of comparing

2   said isolated and amplified signal with stored values representing expected

3   workpiece surface irregularities to distinguish between expected surface

4   irregularities and unexpected surface irregularities.
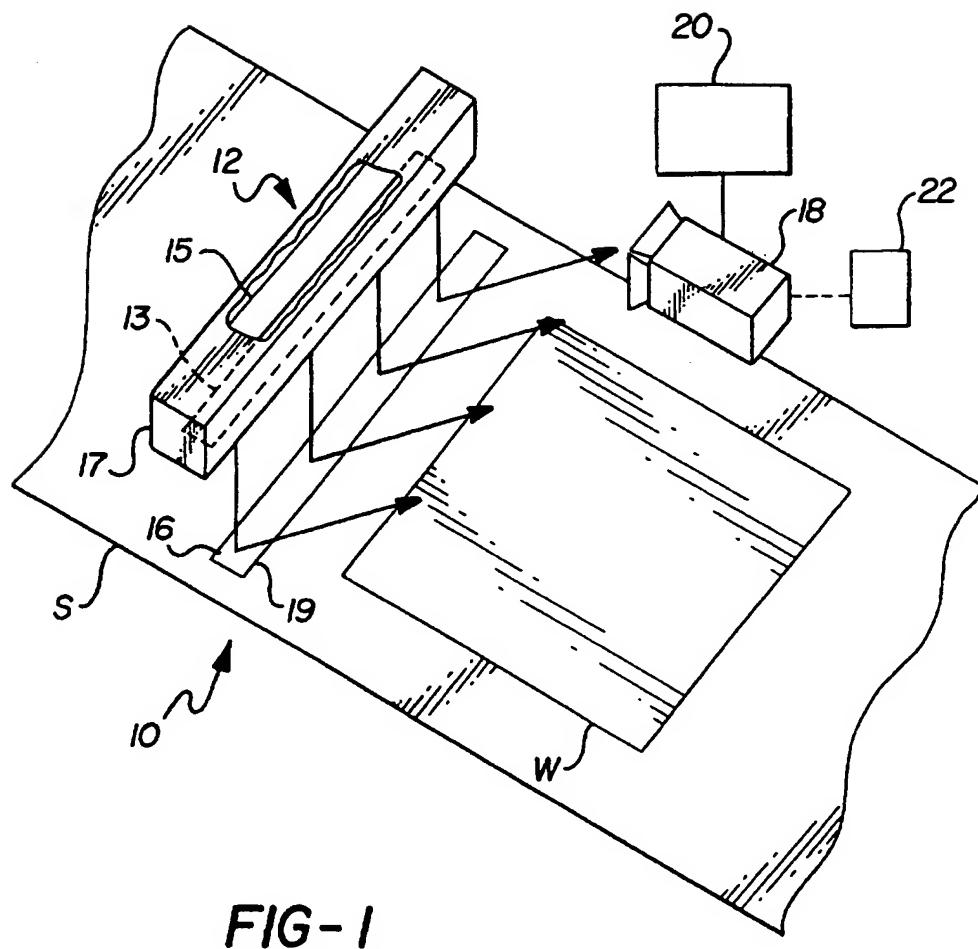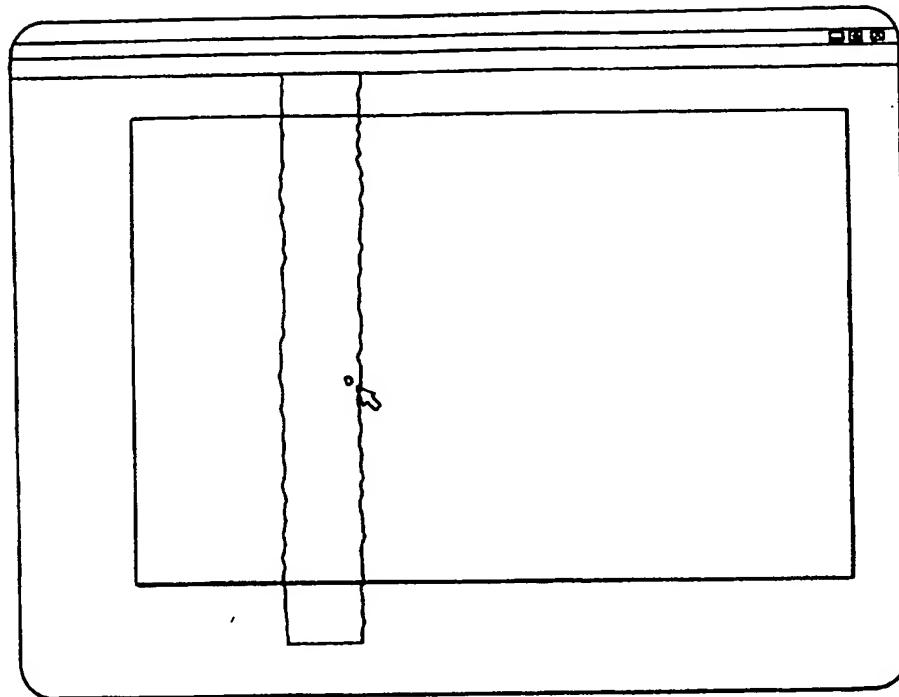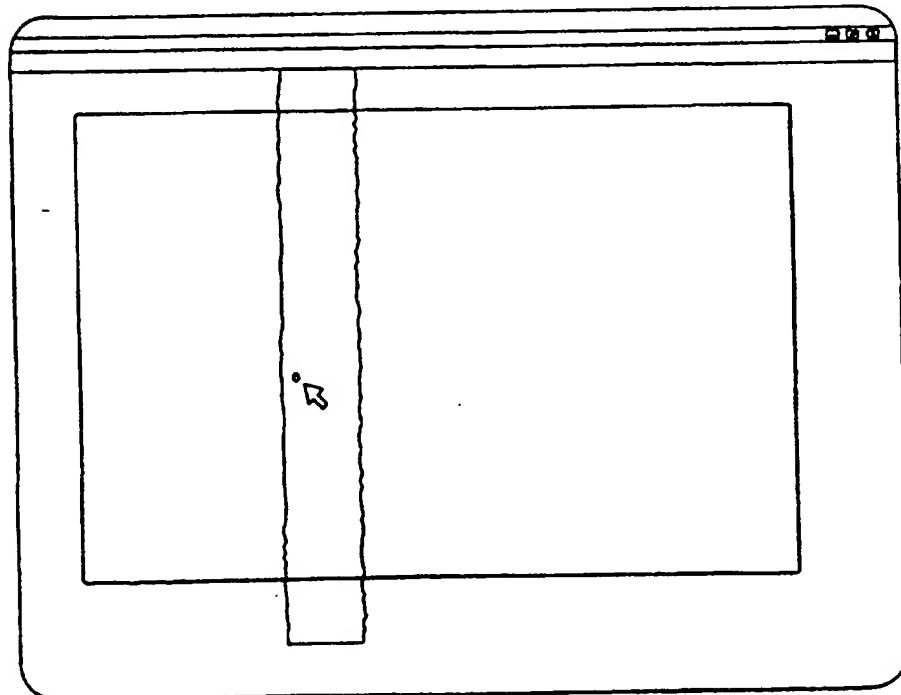
20

12

15

13

18

22

17

16

S

19

10

W

FIG-1

FIG- 2 A

FIG - 2 B

FIG-3A

FIG-3B

FIG - 4

FIG-5A

FIG-5B

FIG-6A

FIG-6B

9/10

FIG-7

FIG-8
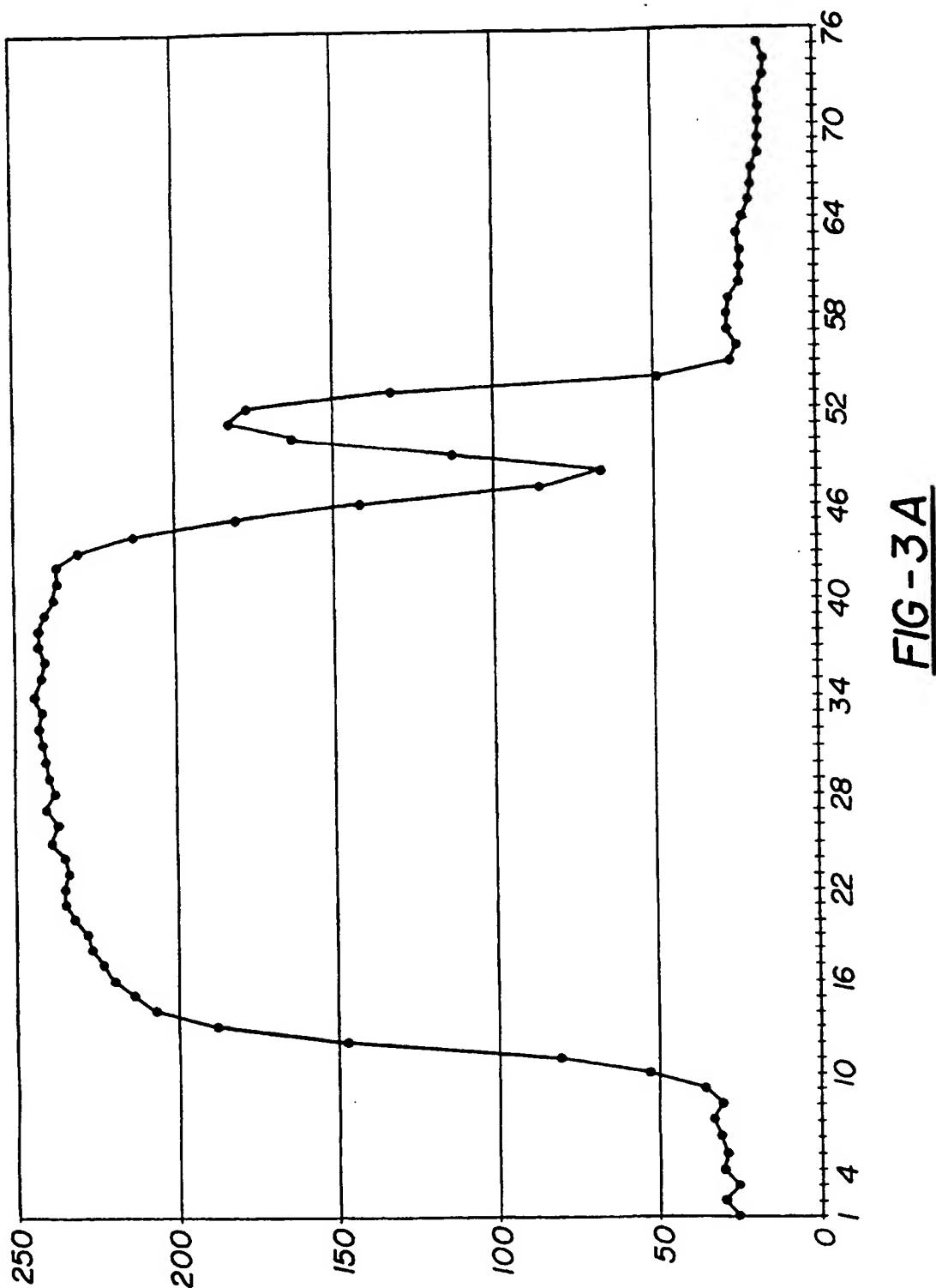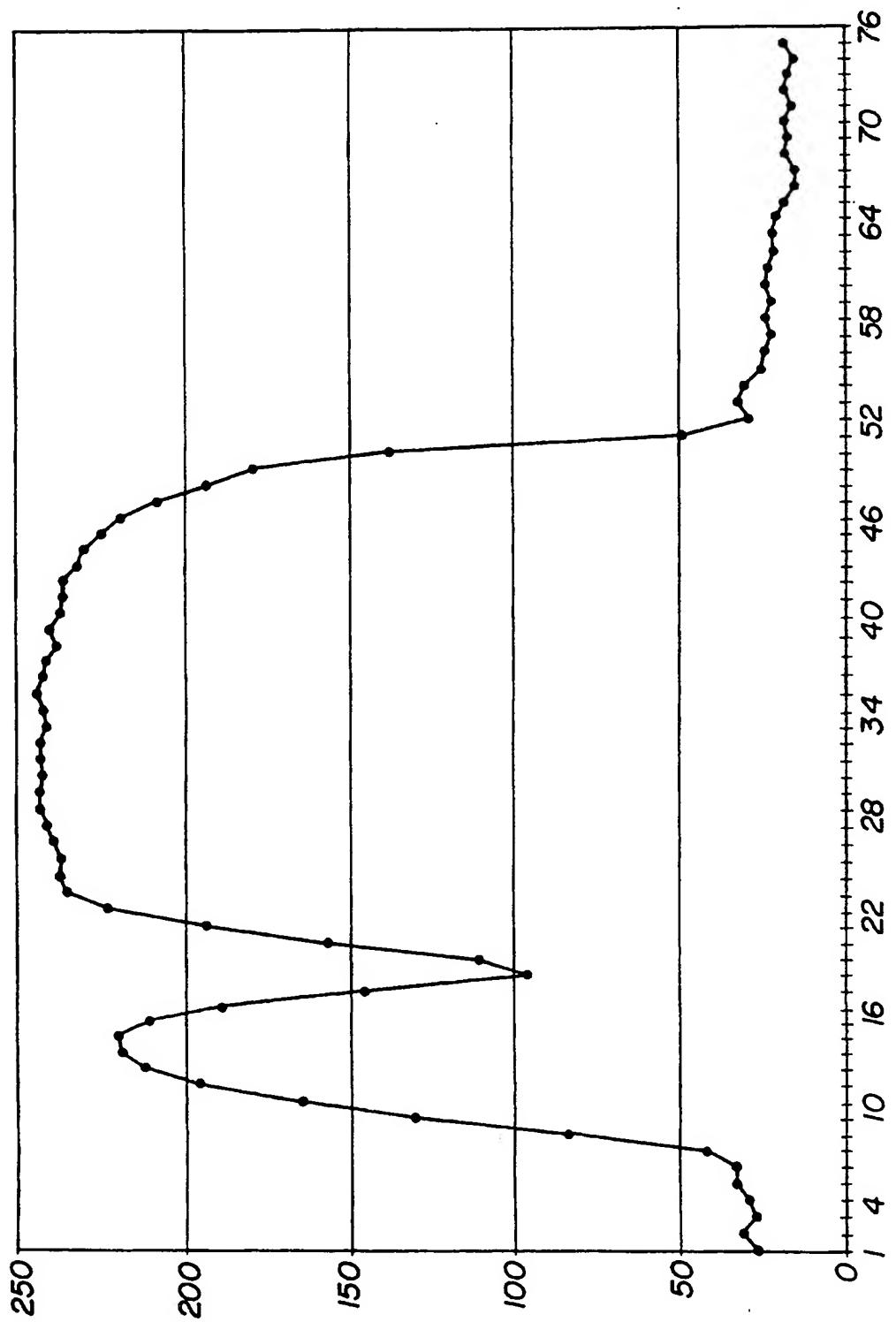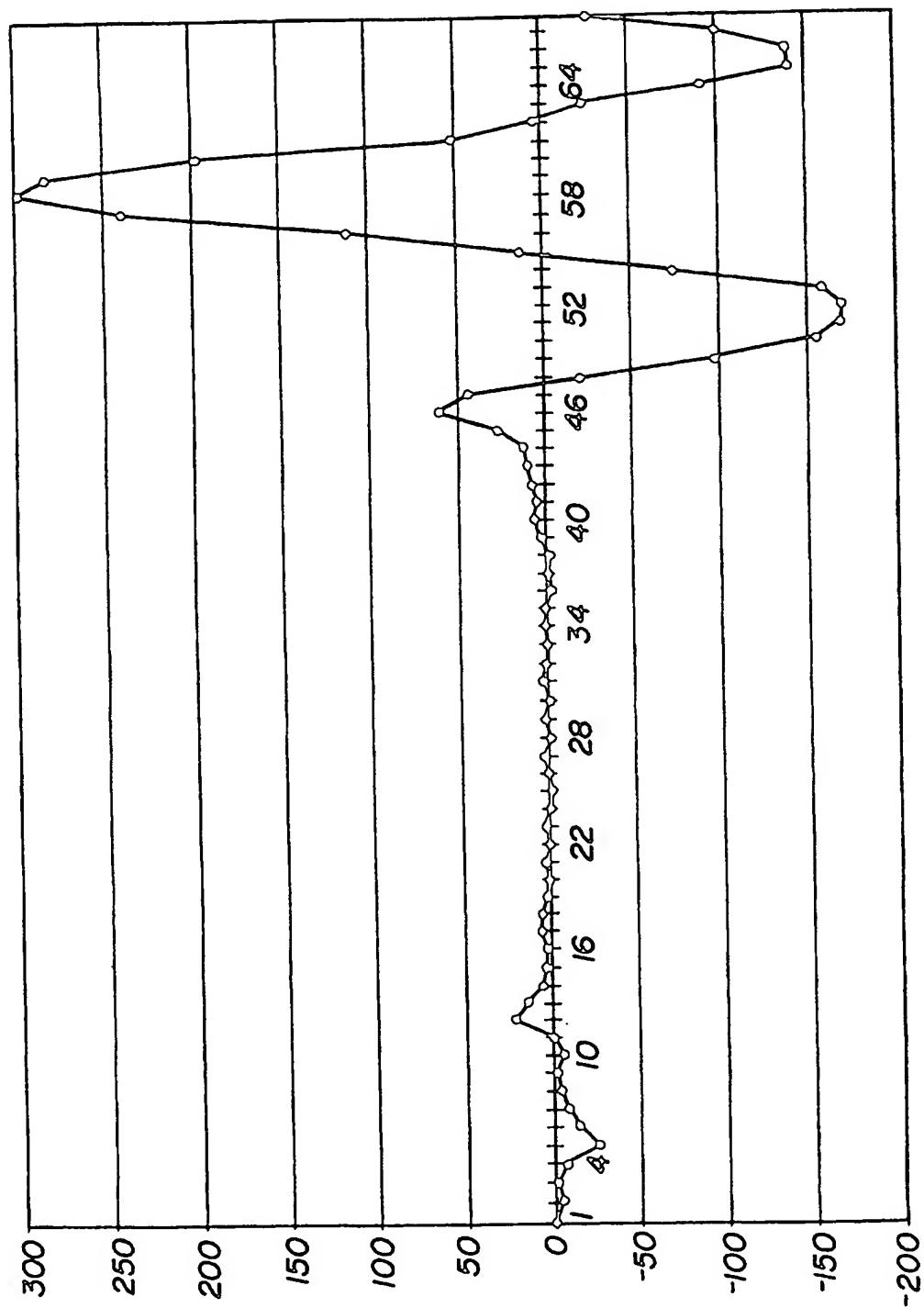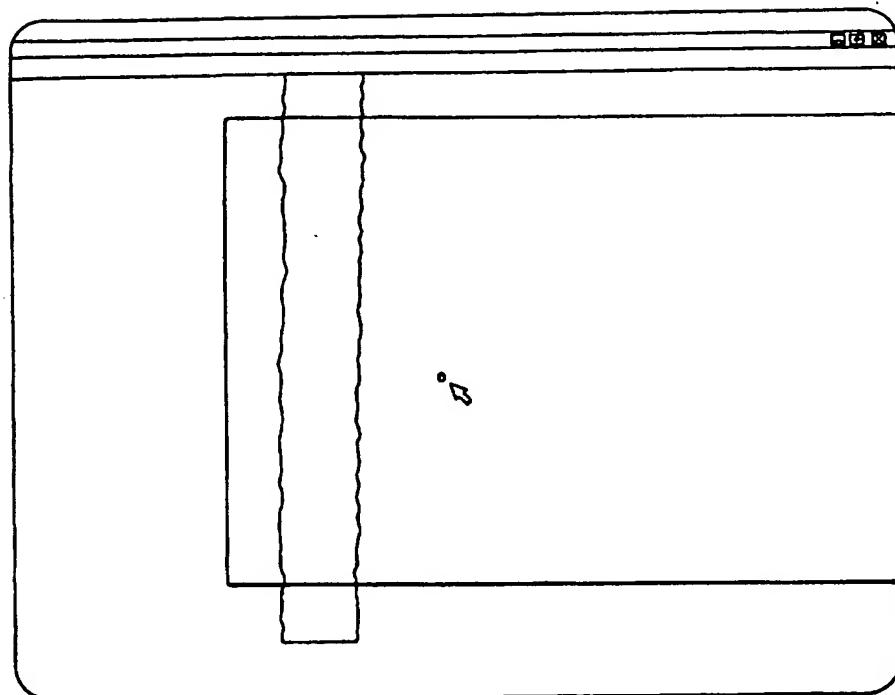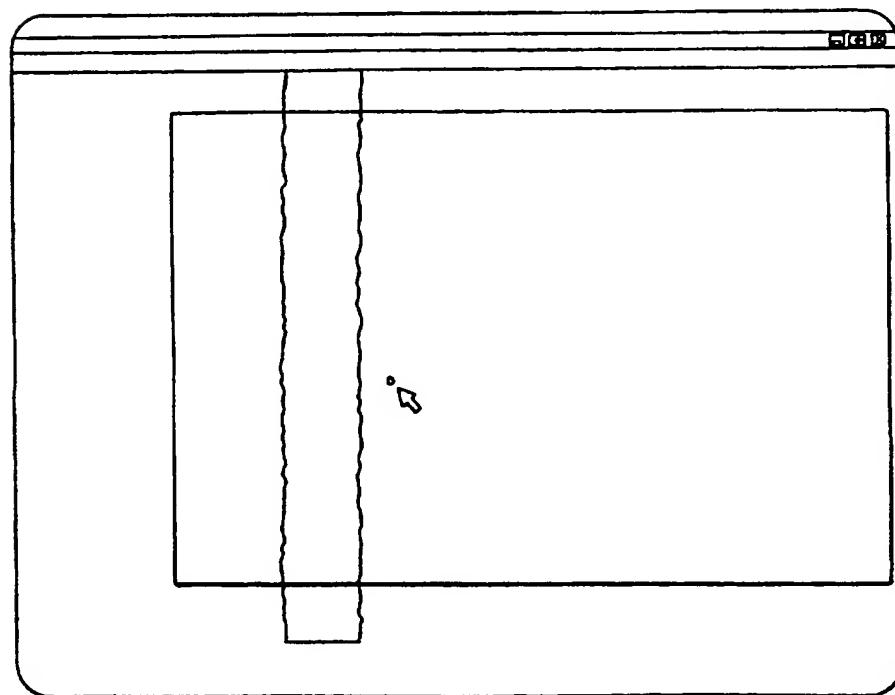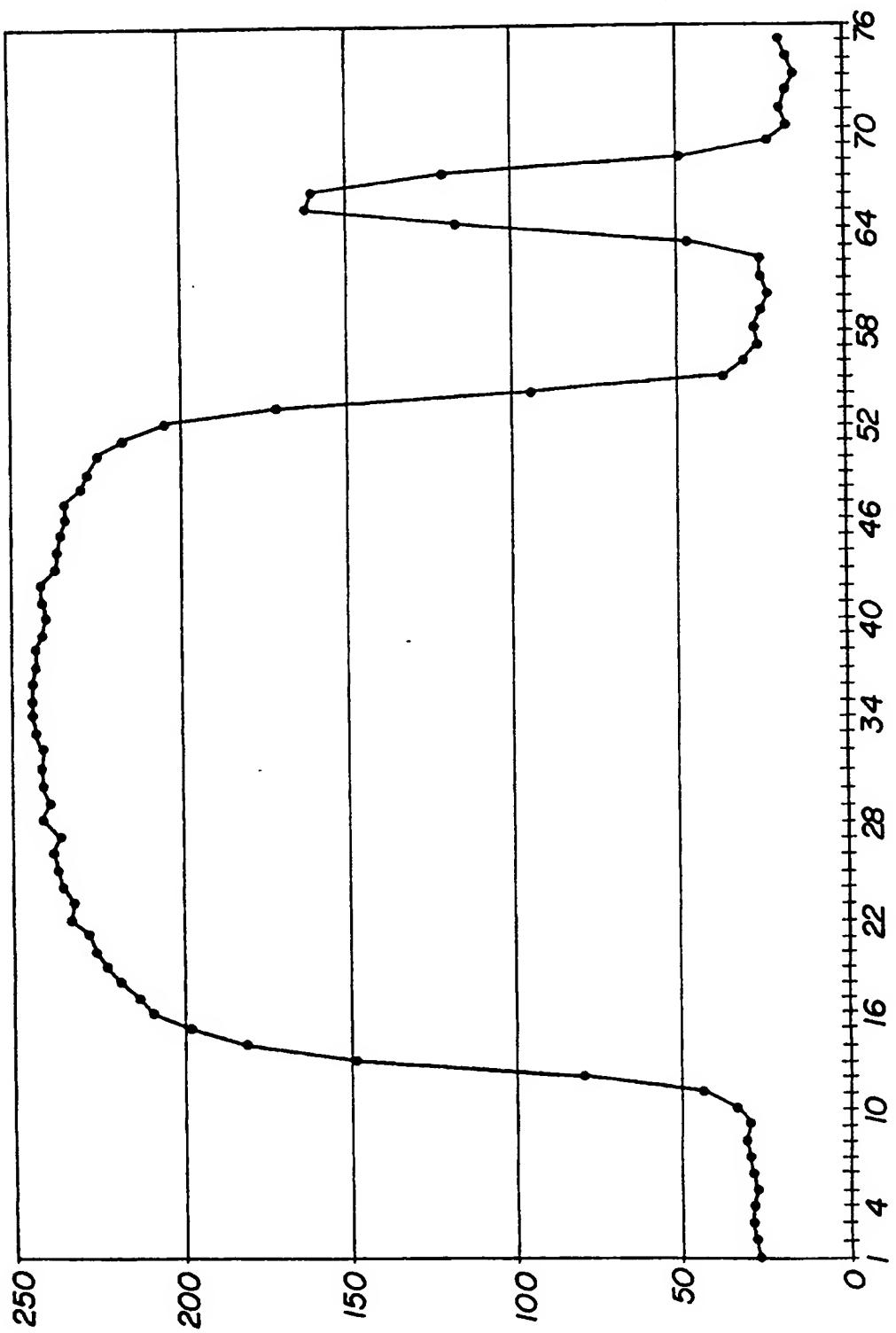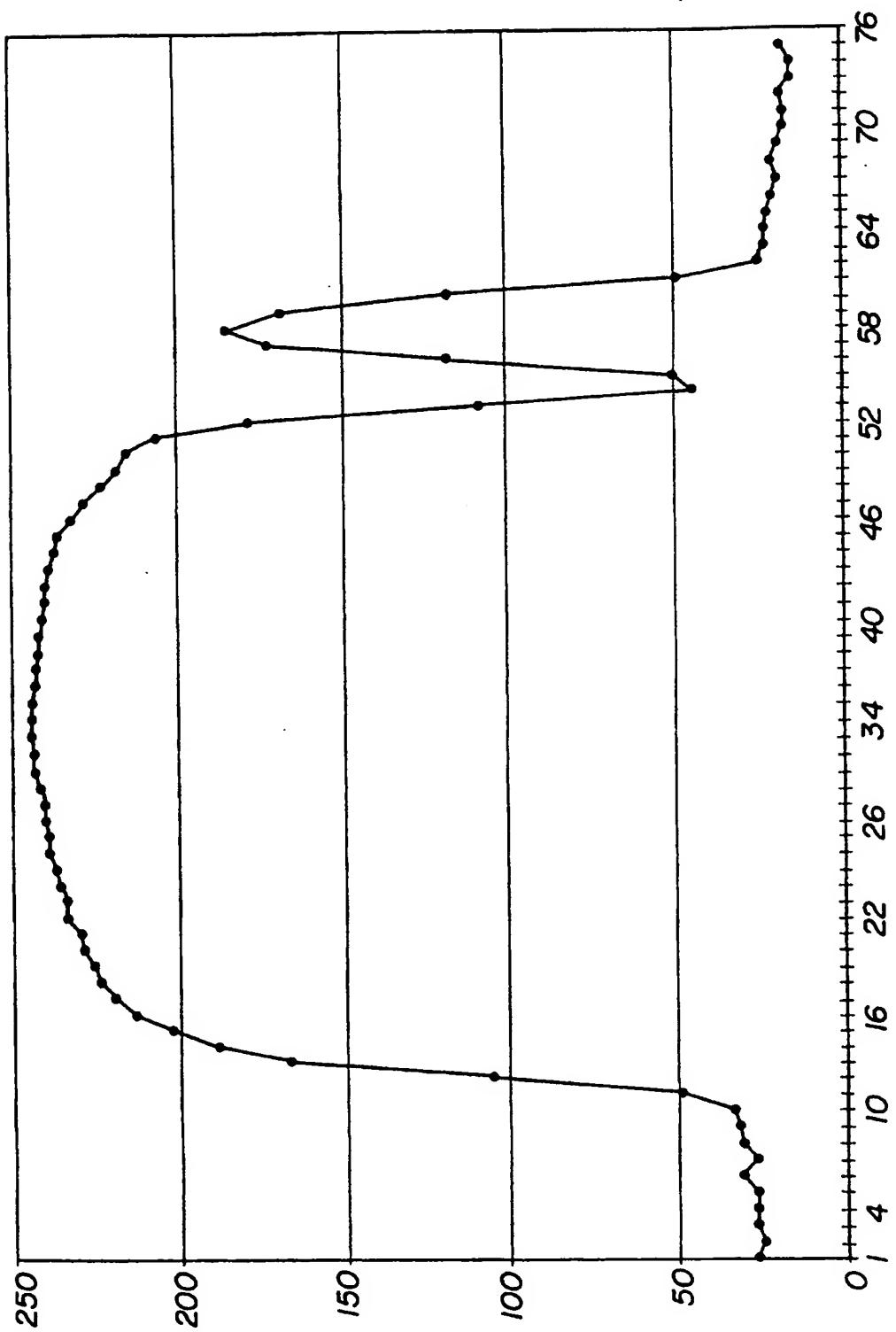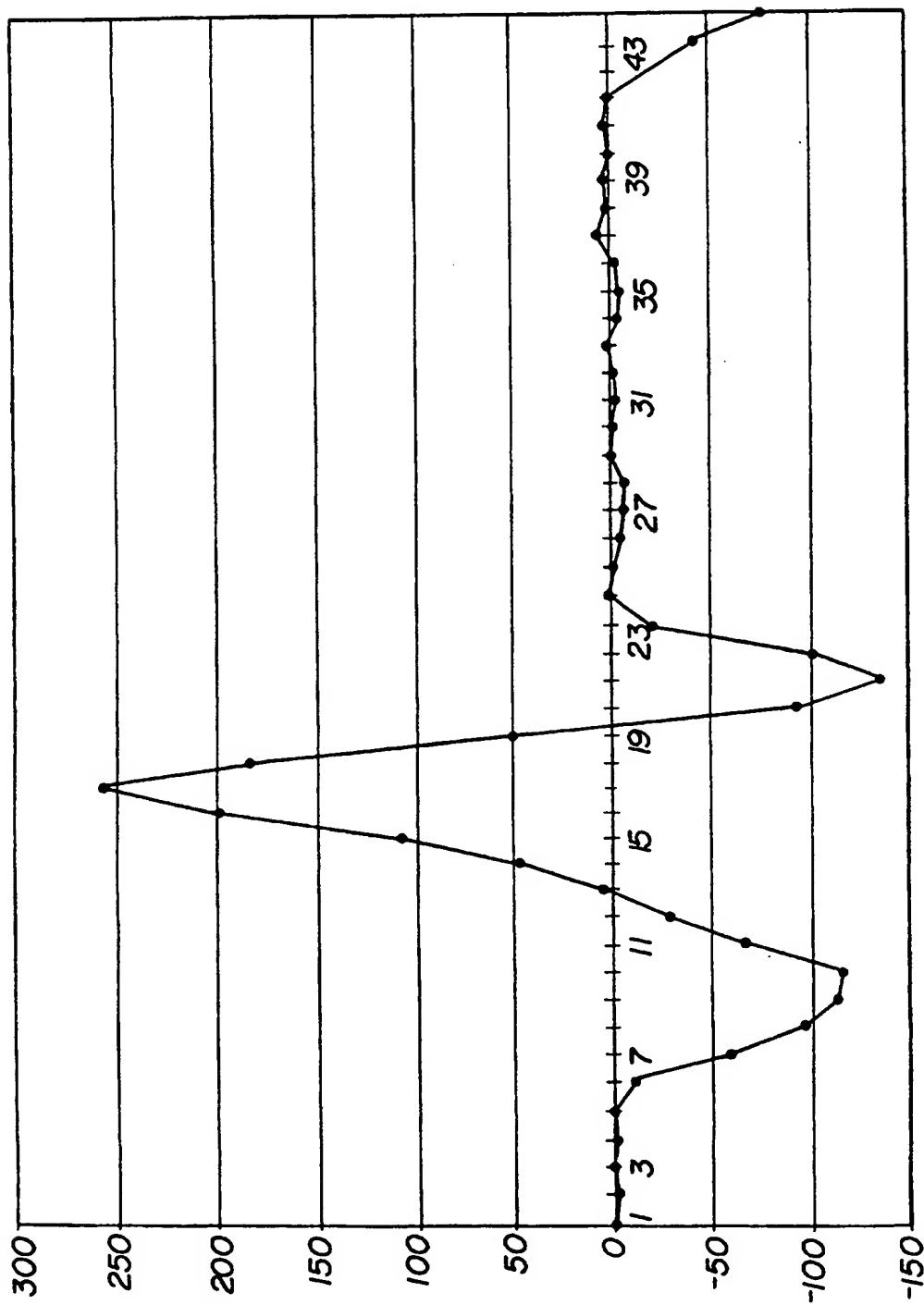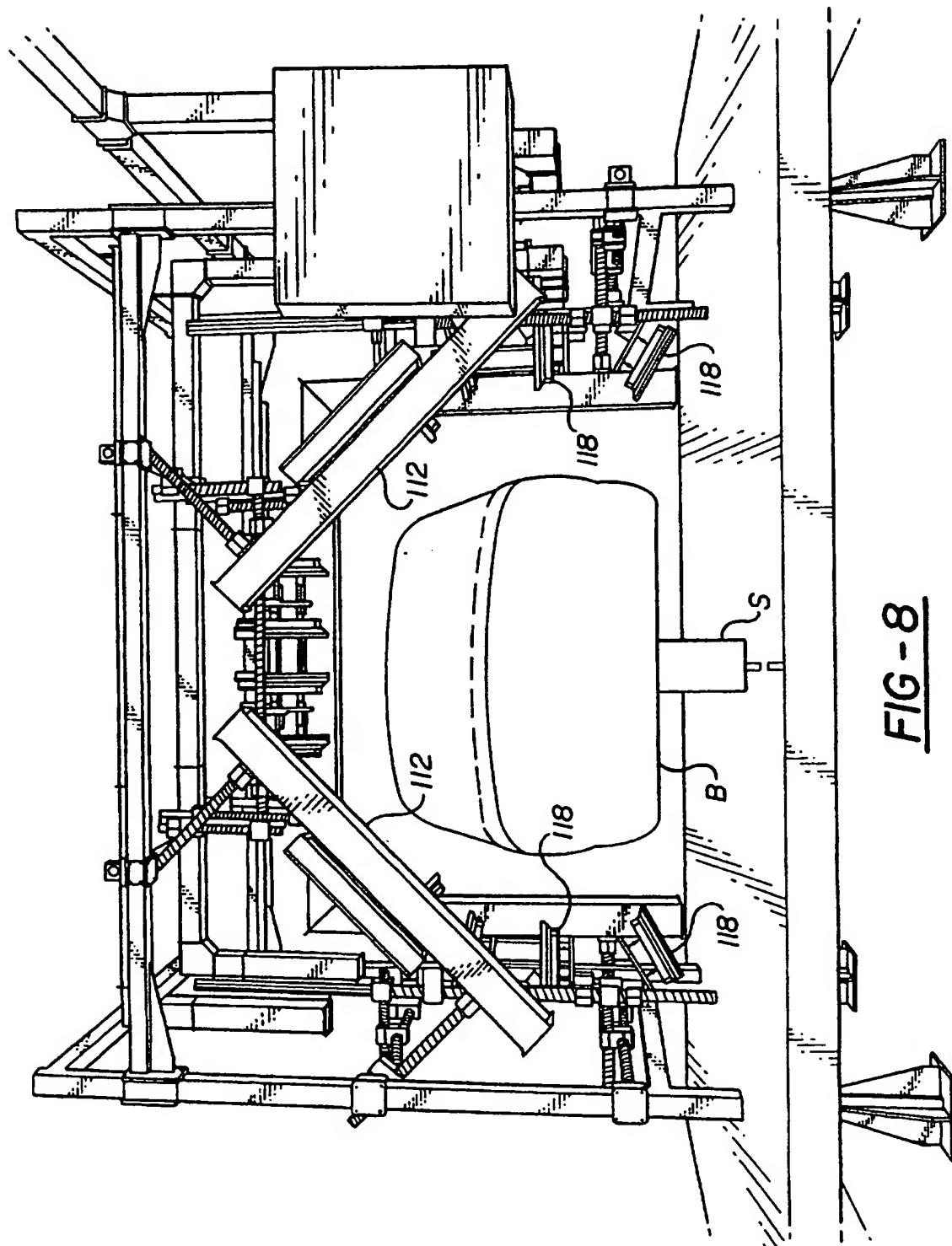
INTERNATIONAL SEARCH REPORT

	International application No. PCT/US97/05899

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01N 21/84, 21/86, 21/00; G06K 9/00; H04N 7/18, 9/47

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/429-431, 237, 239; 250/559.39-559.48; 382/108, 141, 149; 348/128-131

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
Search: defect, flaw, sheet, scan?

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,766,324 A (SAADAT et al) 13 August 1988 (13/08/88), cols 4-9.	1-17
Y	US 4,528,455 A (LOOSE) 09 July 1985 (09/07/85), cols 3-7.	1-17
Y	US 3,331,963 A (LIPPKE) 18 July 1967 (18/07/67), col 2 and Fig 2.	1-17

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 MAY 1997	02 JUN 1997

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer JASON D. VIERRA EISENBERG
Facsimile No. (703) 305-3230	Telephone No. 703-305-0596

Form PCT/ISA/210 (second sheet)(July 1992)*